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Research Article

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Nitrate leaching in soil of different cropping systems of middle Gangetic plain of India

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Summary

Solute transport down a soil plays a significant role in determining the potential contamination of ground water resources, particularly for the nitrate, heavy metals, arsenic and fluoride. The ability to predict the relative mobility of dissolved solute in the soil solution is of considerable value in managing land disposal of wastes and in fertilizer applications. Such predictive capability requires knowledge of physical, chemical and biological processes influencing solute behaviour in the soil environments. In this study, attempts have been made to explore nitrate transport through vertical soil column of several soils of different cropping systems *viz.*, rice-wheat, rice-vegetable, vegetable-vegetable, pulse-pulse, orchards and sugarcane. Vertical soil leaching column studies were carried by spiking the nitrate solution (531.6 mg NO_3^-) on the top of the saturated soil columns followed by constant water head flow of water at definite time interval (1, 2, 3, 4, 5, 10 and 24 hours). It was observed that the nitrate retention on soils column was comparatively higher in the soils of orchard (82.1%) and rice-vegetable (approximately 70%) cropping system areas, whereas retention was noticed very low (>20%) in the soils of pulse-pulse cropping system areas. In addition, the break through curve (BTC) of NO_3^- leaching through different soil columns were drawn with respect to relative concentration (C_o/C_1) of NO_3^- leachate against the pore volume (Pv) of the soil columns in the period (1 to 24 hours) of leaching.

Key words : Nitrate transport, Soil column, Leaching, Breakthrough curve, Cropping system

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Introduction

Nitrogen (N) is an essential input for the sustainability of agriculture also a major pollutant in terrestrial ecosystem. Nitrogen accumulates in soil mainly through rainfall, plant debris, animal residues and microbial fixation from atmosphere. Significant amount of soil organic nitrogen are mineralized, which are taken up by the crops and leached in ground water. Because NO_3^- is negatively charged, it is not retained by the soils, and thus NO_3^--N is the dominant form N leached. Nitrate contamination of groundwater is a worldwide problem Liu *et al.* (2005) . Nitrate is soluble and negatively charged and thus has a high mobility and potential for loss from the unsaturated zone by leaching (Chowdary *et al.*, 2005). Many studies showed high correlation and association between agriculture and nitrate concentration in groundwater (Jordan and Smith, 2005) that has an impact on the economy, ecosystem and human

health.This problem is predominant in areas where intensive cropping is growing with liberal use of nitrogenous fertilizers (Burkart and Stoner, 2007).

The amount of nitrate leaching depends on many factors such as soil texture and hydraulic conductivity of soils. Many studies show that solute transport depends on water flow velocity, hydromorphic dispersion, soil moisture content etc. Movement of solutes in soils has received increasing attention during recent years because of its potential effects on surface and ground water quality. Solutes (*viz.*, fluoride, iodide, arsenic, nitrate, nickel, cadmium etc.) have been measured in laboratory by using soil leaching columns (Mukhopadhyay and Sanyal, 2002) and lysimeters. Excess nitrates leach down the soil profile with percolating water. Leaching of nitrates is higher in sandy soils, but it takes place in fine textured soils also.

The soils of the middle Gangetic plain of India are most fertile for crop production. Thus, there is long history of nitrogenous fertilizers application in crop cultivation *viz.*, rice, wheat, sugarcane, pulse, vegetable and also commercial orchard (mango, guava etc.). Keeping in view these facts and the importance of nitrate contamination in human health, in this study, attempts have been made to explore nitrate transport through vertical soil column of several soils of different cropping systems.

Resource and Research Methods

Physiographic situation :

Geographically the district Varanasi is situated at 25°18' of Northern latitude, 83° 36' of Eastern longitude and at an altitude of 80.71 m above the mean sea level (MSL) in the middle Indo-Gangatic plain of eastern Uttar Pradesh, India. The district Varanasi having alluvial soil lies in semi arid region to sub humid belt of Northern India.

Climatic conditions :

The district Varanasi falls in a semi-arid to sub-humid climate with moisture deficit index of 20-40 per cent. It is often subjected to extreme of weather condition. The mean annual precipitation is 1100 mm. The area occasionally experiences winter cyclonic rain during December to February. In term of percentage of total rainfall, about 84 per cent is received from June to September, 0.7 per cent October to December, 6 per cent from January to February and 9.3 per cent from March to May as premonsoonic rain .The mean relative humidity (RH) of this area is about 68 per cent with maximum 82 per cent and minimum 30 per cent during July to September and April to early June, respectively. The minimum and maximum average temperature of the area range from 4.4 to 28.2^{0}C, respectively. The temperature begins to rise from February onward until the summer often exceeding 45^{0}C in the month of May and June. During these extremely hot months desiccating winds blow from west to east and dust storm frequently occurs.

Collection of soil samples :

The soil samples were collected from cultivated fields of different cropping systems *viz.*, rice-wheat, rice-vegetable, vegetable-vegetable, pulse-pulse, orchards and sugarcane in Varanasi district. The soils were collected from three depths (0-15, 15-30 and 30-45 cm) during premonsoon period from cultivated areas with high intensity cropping systems where, the long history of nitrogenous fertilizer application.

Soil leaching column study of nitrate :

Leaching experiment (Mani and Sanyal, 1966) was conducted at room temperature (25^{0}C) in a PVC column (length 50 cm and *i. d.* 2.5 cm) packed with selected soils. To simulate the top depth of the soil, each experimental soil column will be kept at 30 cm depth with approximate 200g soil depending on the bulk density of soil. Each type of soils was load into the column with a 5 cm water level maintained on the top of the column in order to approximate the same rainfall intensity experimentally. The leachates were collected at different time intervals, and the experiment was continued over night for each soil. The volumes of leachates, at different time intervals were recorded, while the corresponding nitrate concentration was determined by colorimetrically.

The data were used to obtain the hydraulic conductivity (K) of the given soils for the electrolyte (NO_3^-) used. The K values were obtained by employing the Darcy's law (eq. 1) to the given soil-flow system. Thus,

$$q = \frac{K.\Delta H}{L} \qquad ...(1)$$

where q is the volume flux density (cm sec^{-1}) through the soil column, ΔH is the hydraulic head difference (cm) causing the flow of the electrolyte and L is the length of the column (cm).

The solute (NO_3^-) accumulation parameter 'r' (eq. 2), was developed by Johnson *et al*. (1966) by the soil column (permeated by a given solution) is given as:

$$\mathbf{r = 1 - \frac{C_e}{C_0}} \qquad ....(2)$$

where C_e and C_0 are the solute concentrations in effluent and the feed solution, respectively. In general, higher the value of r, the greater is the extent of the solute accumulation in the soil leading to a higher efficiency of 'hyperfiltration'.

Breakthrough curves for the nitrate (NO_3^-) :

The above results were plotted showing (C_e /C_0) against the pore volumes P_v, of the effluent (leachate), obtained from (eq. 3) which reads as,

$$\mathbf{P_v = V/V_0} \qquad .....(3)$$

where V is the volume of the leachate collected in given time't' and V_0, the volume of the voids,containing the displacing fluid in the soil column.The latter was obtained from eq. (4), namely,

V_0=¦¯.V ....(4)

where ηθ is the water filled porosity at the given time and V is the total volume of the soil column. The value of ηθ at the appropriate time intervals used in the experiments was obtained by soaking the soil (from bottom) with appropriate solution (double distilled water) over the given time periods.

$$\mathbf{\eta\theta\ (water\ filled\ porosity\ cm^3\ cm^{-3}) = \frac{Volume\ of\ watered\ by\ dry\ soil}{Total\ volume\ of\ soil\ column}} \qquad ...(5)$$

Research Findings and Discussion

The important physico-chemical properties of the soils of different cropping systems under study are given in Table 1. The soils were slightly alkaline in nature with widely varying organic carbon and clay contents with the different cropping system and hence, CEC.

The results of vertical soil leaching column studies by spiking the nitrate solution (531.6 mg NO_3^-) on the top of the saturated soil columns followed by constant water head flow of water at definite time interval (1, 2, 3, 4, 5, 10 and 24 hours) was presented in Fig 2 .

The data on aqueous nitrate transport were expressed graphically in Fig. 1, these solution transmission characteristic curves showed the following trends in permeability in different soils for the aqueous nitrate used. Rice-wheat (Pindra) > pulse-pulse >

Table 1: Physio-chemical characteristics of selected soils of different cropping systems

Cropping system	pH			Organic carbon (g/kg)			Bulk density (Mg m^{-3})			WHC (%)			CEC [Cmol (p$^+$kg^{-1})] (Surface soil)	Textural class (USDA) (Surface soil)
	Depth of soil (cm)													
	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	15-30	30-45	0-15	0-15
Rice-wheat	7.95 ±0.40	8.03±0.50	8.13±0.55	6.05±3.75	4.71±2.75	4.49±3.49	1.33±0.08	1.36±0.08	1.35±0.07	47.19±3.71	46.32±4.20	46.56±5.63	10.35±2.62	Clay loam
Rice-vegetable	8.21±0.49	8.13±0.30	8.21±0.37	6.01±2.88	5.17±3.08	3.41±2.62	1.35±0.07	1.33±0.10	1.34±0.07	47.84±3.78	48.10±4.25	48.18±4.59	10.04±4.05	Loam
Vegetable-vegetable	8.11±0.47	8.05±0.40	8.07±0.47	4.42±2.21	4.96±2.52	4.77±2.40	1.30±0.11	1.32±0.08	1.33±0.10	48.50±4.15	47.69±4.21	46.90±3.79	9.65±2.08	Loam
Pulse-pulse	8.03±0.45	8.13±0.40	8.17±0.54	6.18±2.67	6.02±3.48	6.13±3.63	1.31±0.11	1.32±0.08	1.31±0.08	47.08±2.52	45.43±4.50	48.67±4.29	8.80±1.55	Clay loam
orchard	7.92±0.30	7.90±0.33	8.08±0.60	5.93±3.74	4.84±2.78	5.11±2.90	1.34±0.07	1.33±0.09	1.37±0.05	46.55±2.04	45.26±4.72	45.51±3.48	9.32±1.38	Clay loam
Sugarcane	8.05±0.27	8.05±0.43	8.28±0.35	6.49±3.62	6.59±4.08	5.11±3.05	1.26±0.07	1.29±0.09	1.31±0.08	49.33±3.19	48.22±3.61	47.33±4.22	9.23±1.60	Loam
Range	7.92-8.21	7.90-8.13	8.07-8.28	4.42-6.49	4.71-6.59	3.41-6.13	1.26-1.35	1.29-1.36	1.31-1.37	46.55-49.33	45.43-48.22	45.51-48.67	8.80-10.35	
Mean	8.04	8.05	8.16	5.85	5.38	4.83	1.32	1.33	1.34	47.75	46.84	47.19	9.57	
±S.D.	0.11	0.09	0.08	0.73	0.75	0.89	0.03	0.02	0.02	1.03	1.34	1.14	0.57	
C.V.	1.32	1.06	1.00	12.42	14.02	18.44	2.49	1.70	1.76	2.15	2.86	2.41	5.92	

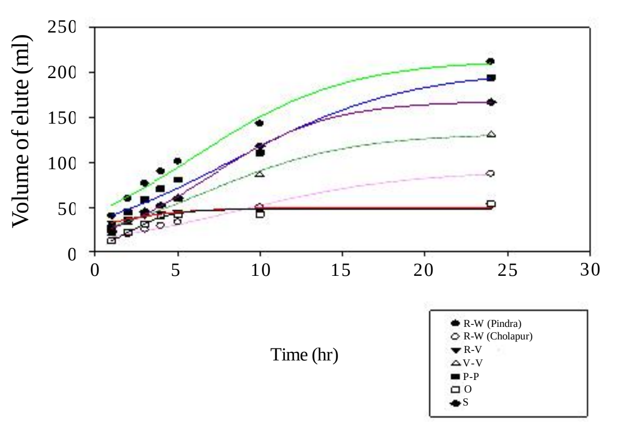


Fig. 1 : Periodical valume of elute collected from soil columns of different cropping systems

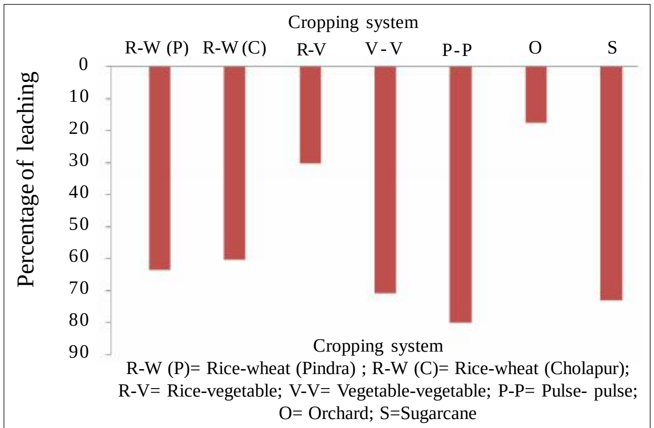


Fig. 3 : Percentage of nitrate leaching from soils of different cropping systems of Varanasi district

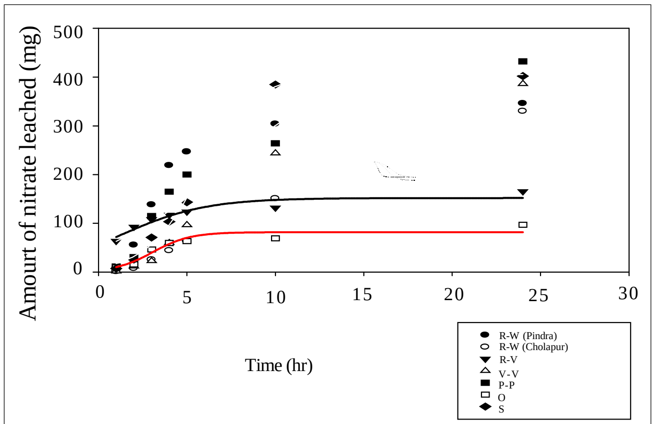


Fig. 2 : Periodical nitrate leaching from soil columns of different cropping systems

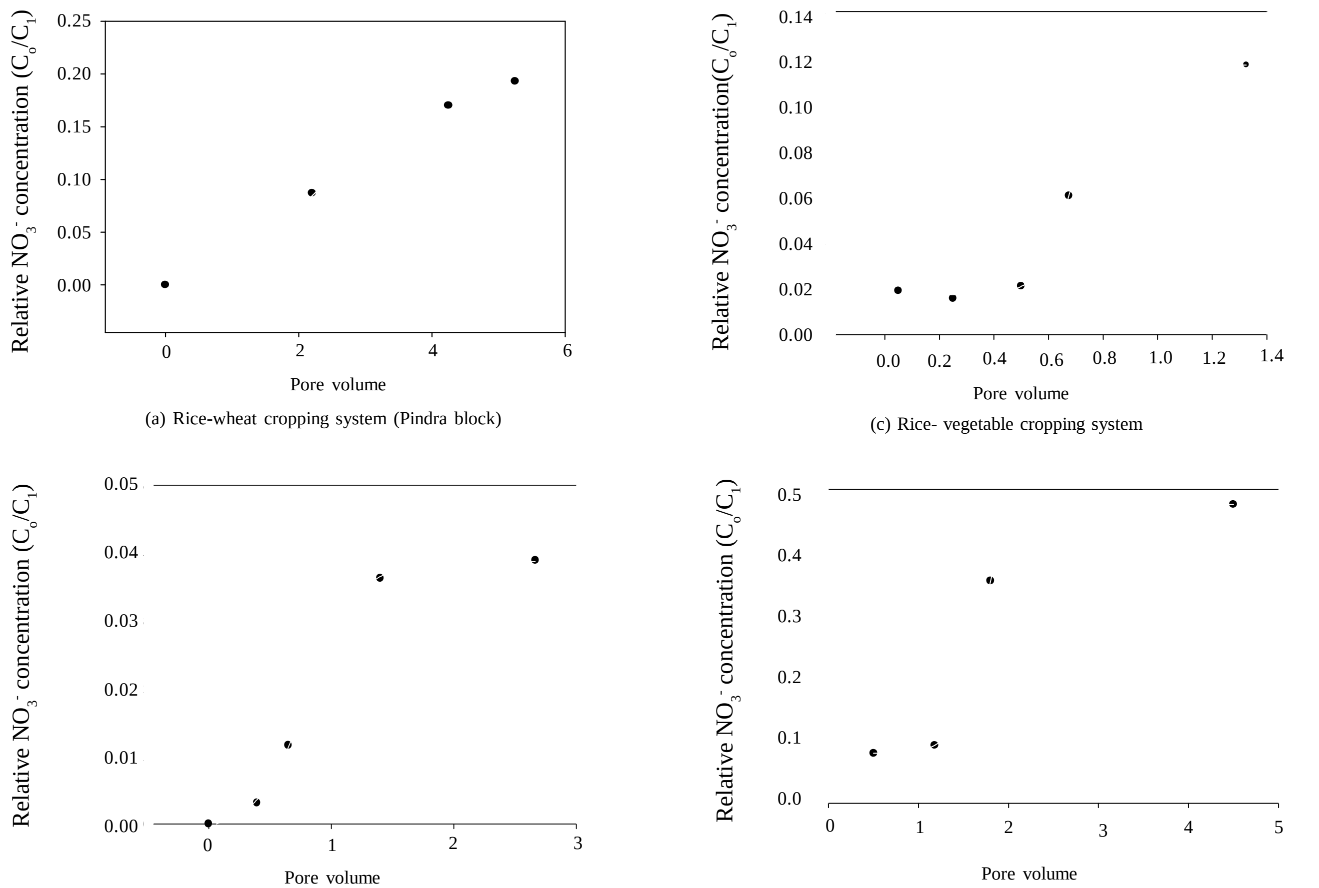
sugarcane > vegetable-vegetable > rice-wheat (Cholapur) > orchard > rice-vegetable.

Cumulative volume of leachates collected after 24 hours was calculated after collecting the all leachate from different soil columns. Highest amount (212 ml) of leachate collected from soil columns was in the soil of rice-wheat (Pindra) cropping system and lowest was noted in soils of orchard (53.2 ml). Further, the order of the per cent nitrate leaching (Fig. 3) from soil column was: pulse-pulse > sugarcane > vegetable-vegetable > rice-wheat (Pindra) > rice-wheat (Cholapur) > rice-vegetable > orchard. Thus, nitrate retention was comparatively higher in the soils of orchard (82.1 %) and rice-vegetable (69.6 %) cropping system areas whereas nitrate retention was noticed very low (> 20 %) in the soils of pulse-pulse cropping system areas. Thus, the dose and methods of the N-fertilizers are most important criteria for ground water contamination of nitrate through leaching. There was a wide variation of retention of nitrate in soil columns, *i.e.* 19.74 to 82.12.

In addition, the break through curve (BTC) of NO_3^- leaching through different soil columns were drawn (Fig. 4 and Fig. 5) with respect to relative concentration (C_0/C_1) of NO_3^- leachate against the pore volume (Pv) of the soil columns in the period (1 to 24 hours) of leaching. The approximately sigmoid shape of the break through curves for aqueous nitrate solution in the given soils was found.

The general observation as regards the less solute permeability of the orchard and rice-vegetable soils may possibly be attributed to the presence of higher organic matter containing humic and fulvic acids and clay contents in these soils. Furthermore, the higher particle density tended to be sluggish in transporting the given aqueous solutions, particularly so at longer intervals, due to probably to higher degree of compactness that might have rendered the different soils, less permeable on prolonged passage of solution. The amounts of nitrate leached with respect to different time intervals are presented in Fig.2 showed that effluent concentration varied with the progress in time. Initially, quite a sharp fall in NO_3^- concentration was noted in the soils of orchard and rice-vegetable cropping system areas, suggesting a high degree of nitrate accumulation in these soils.

Sigmoid shape of the break through curves indicated the hydrodynamic dispersion, that is, mixing of the permeating solution, with the soil solution originally present, leaching to displacement of the latter. The presence of 'deadened pores' in soils leads to no



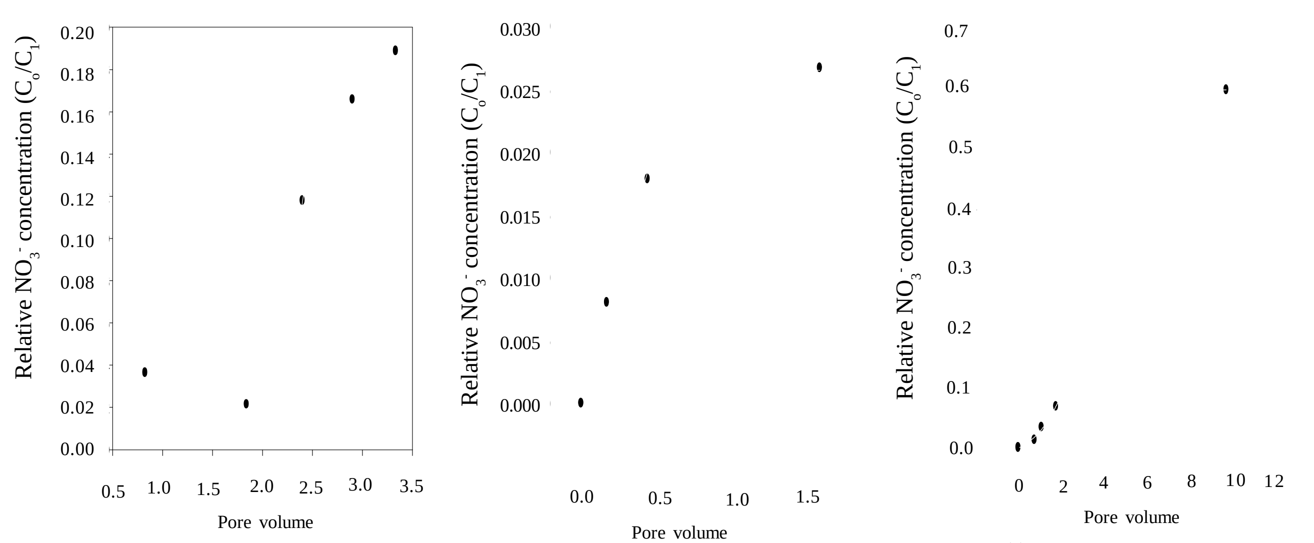
(a) Rice-wheat cropping system (Pindra block)

(c) Rice- vegetable cropping system

(b) Rice-wheat cropping system (Cholapur block)

(d) vegetable-vegetable cropping system

Fig. 4 : Nitrate breakthrough curves for the soils of different cropping system (a, b, c and d) of Varanasi district



(e) Pulse-pulse cropping system

(f) Orchard cropping system

(g) Sugarcane cropping system

Fig. 5 : Nitrate breakthrough curves for the soils of different cropping system (e, f and g) of Varanasi district

contribution from a significant fraction of the total pore volume of a soil towards the volume of the effluent measured at different time intervals. A shift of BTCs to the left (Ghildyal and Tripathi, 1987) of the inflection point was observed which were noticed greater for the soils having higher organic matter content (rice-vegetable and orchard cropping system) and $CaCO_3$ content, suggesting a higher degree of NO_3^- retention by these soils. The present study also revealed that an increase in soil compaction led to a greater degree of shifts of the given BTCs to the left of the inflexion point. This may have arisen from a greater time of contact between the static and the mobile phases at a higher compaction level, causing a greater extent of hydrodynamic dispersion.

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